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(54) IMPROVEMENTS IN OR RELATING TO CATHODES FOR USE IN ELECTRIC DISCHARGE DEVICES

(71) We, THE GENERAL ELECTRIC COMPANY LIMITED (formerly The General Electric and English Electric Companies Limited) of 1 Stanhope Gate, London, W.1., a British Company, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

This invention relates to cathodes for use in electric discharge devices. The invention relates particularly to cathodes for use in electric discharge devices of the kind comprising a body of semiconductive material containing a p-n junction, part of which junction is exposed at the surface of the body. If a voltage is applied across such a junction in the reverse-bias direction, free electrons in the p-type region will be accelerated by the high electric field in the region of the junction into the n-type material, and if the voltage is sufficiently large some of the electrons will be accelerated to high enough energies to be able to escape from the material should they come close enough to the surface of the body. This effect may in some cases be enhanced by localised breakdown of the material at the surface of the body.

Electrons are thus emitted from the cathode without any appreciable rise in the temperature of the material as a whole.

Such cathodes have found particular application in cathode ray tubes, one such cathode being described in the specification of Patent No. 1,134,681.

According to the invention a cathode for use in an electric discharge device comprises a body of semiconductive material having at least one pair of regions of opposite conductivity types, separated from each other by a p-n junction which intersects a substantially planar part of the external surface of the body in a closed loop, the cathode being such that a suitable reverse-bias voltage applied across the junction causes electrons to be emitted

from the cathode, only in the vicinity of said loop where the p-n junction is exposed at the planar surface.

One advantage of a cathode in accordance with the invention is that the loop, and hence the effective area of the cathode, may have any of a wide range of shapes or sizes. In particular, it may be desired to provide effectively a point source of electrons in which case the loop is made small in extent.

Preferably the p-n junction is annular in shape. The advantage of this arrangement is that it permits the total area of the p-n junction, for a given length of the loop, to be small, resulting in improved efficiency of electron emission from the cathode. By a junction of annular shape is meant a junction which is bounded by two edges, each of which is a closed loop although not necessarily a circular loop.

In a particular cathode in accordance with the invention the cathode further includes a layer of a material of high resistivity, one said region comprising a layer of semiconductive material overlying the resistive layer, the surface of which semiconductive layer remote from the resistive layer lies in said substantially planar part of the surface, and the other said region comprising a body of semiconductive material extending from said substantially planar part of the surface through the first region into the resistive layer. The junction separating the two said regions is thus annular in shape in this particular cathode.

In this case, said other region of semiconductive material may extend through the resistive layer also, to the side of that layer remote from said substantially planar part of the surface. Electrical contact may then be made to said other region from the side of the resistive layer remote from said substantially planar part of the surface, conveniently via a further layer of semiconductive material overlying that side of the resistive layer which makes ohmic contact with said other region.

In another particular arrangement in ac-

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cordance with the invention said regions comprise at least two regions of one conductivity type and a region of the opposite conductivity type separated therefrom by respective p-n junctions each of which intersects the substantially planar part of the surface in a closed loop. In this arrangement, a voltage can be applied between the two said regions of one conductivity type causing one of the p-n junctions to become reverse biased and the other to become forward biased, so that electrons can be emitted from one or other of the loops, depending on the polarity of the applied voltage. One of said two regions of one conductivity type may lie within the region of opposite conductivity type, which in turn lies within the other of said two regions.

Several embodiments of the invention will now be described, by way of example, with reference to the drawings filed with the Provisional Specification, of which:

Figure 1 is a sectional elevation of a cathode in accordance with the invention;

Figure 2 is a schematic sectional elevation of a cathode ray tube utilising a cathode of the kind shown in Figure 1;

Figure 3 is a sectional elevation of another cathode in accordance with the invention; and

Figures 4 and 5 are respectively sectional elevational and plan views of a further cathode in accordance with the invention.

Referring to Figure 1, the cathode consists of a crystal of silicon carbide 1 of flat, square form, having a planar surface 2. A region 3 of n-type material approximately 0.5 mm. in diameter is formed in the crystal, extending into the crystal from the planar surface 2, and is separated from the rest of the crystal, which constitutes a region 4 of p-type material, by a p-n junction 5. The junction 5 intersects the surface 2 in a closed loop 6 which is circular in shape. Electrical connection to the regions 3 and 4 is made by means of electrodes 7 and 8 respectively, consisting of evaporated layers of conducting material.

The cathode shown in Figure 1 may be constructed as follows. A single crystal of silicon carbide 1, of p-type conductivity, is formed to approximately the desired final shape of the cathode, with a planar surface 2. A recess is cut into the surface 2 by ultrasonic machining or by chemical etching, the edge of the recess corresponding to the desired position of the loop 6 in the completed cathode. A layer of n-type silicon carbide is then grown epitaxially on the surface 2 to such a depth that the recess is filled to the level of the surface 2. The layer is then removed by lapping and polishing so as to expose the surface 2 once more, while leaving a body of n-type material in the recess to form the region 3.

In an alternative method of constructing the cathode, the crystal 1 is formed as before, and the region 3 is formed in it by introducing atoms of a suitable impurity, such as nitrogen.

One method of doing this is to diffuse the impurity into the crystal through a mask on the surface 2, the mask having a window of approximately the desired shape of the region 3. Another method is to use an ion implantation technique, that is, by bombarding the crystal with dopant ions, accelerated by electric fields. A further method would be to deposit a layer of dopant material on the surface 2, again through a mask having a window of suitable shape, and to alloy the dopant material into the crystal.

Referring to Figure 2, one application of the cathode shown in Figure 1 is in a cathode shown in Figure 1 is in a cathode ray tube. The cathode ray tube comprises a sealed glass envelope 10 comprising a tubular neck 11 housing an electron-gun assembly 12, and a flared end portion 13 on the inner end wall of which is coated a phosphor screen 14, indicated by a dotted line in the Figure. The crystal 1 is mounted on a glass support tube 15 with the planar surface 2 facing the screen 14, the electrodes 7, 8 on the crystal being connected by leads 16, 17 to pin sealed through the base of the envelope.

The cathode ray tube also comprises a cup-shaped modulator electrode 18 surrounding the cathode 1, a disc-type anode 19, focussing electrodes 20, 21, and two pairs of deflecting plates 22, 23.

Referring now to Figure 3, another cathode in accordance with the invention comprises a substrate of p-type silicon carbide with an overlying layer 25 of intrinsic (i.e. relatively resistive) silicon carbide, which in turn has an overlying layer 26 of n-type silicon carbide, having a planar surface 27. A region 28 of p-type silicon carbide extends from the surface 27 through the layer 26, and through the layer 25 to make ohmic contact with the substrate 24.

It will be seen that the p-n junction 29, which separates the layer 26 from the region 28, is thus of annular form.

Electrical connection is made to the n-type region 26 by means of an electrode 30 on the planar surface 27, while connection is made to the region 28 by way of an electrode 31 on the back surface of the layer 24.

The cathode shown in Figure 3 may be constructed by any of the methods described above with reference to Figure 1. For example, the layers 25 and 26 may be grown epitaxially on the substrate 24 and then a recess formed in the surface 27, penetrating into the substrate 24, which recess is subsequently filled with p-type material as previously described.

Referring now to Figures 4 and 5, a further cold-emitter cathode in accordance with the invention comprises a substrate 42, of any suitable material which will serve as a support for the cathode, having an overlying layer 32 of a material of high resistivity, such as for example intrinsic silicon carbide, which in turn

carries an epitaxially-grown layer 33 of n-type silicon carbide having a planar surface 34. A region 35 of p-type silicon carbide extends from the surface 34 through the layer 33 and into the layer 32. The region 35 is of generally annular form and separates the layer 33 into two regions, 36 and 37, of n-type material which are separated from the region 35 by annular p-n junctions 38 and 39 respectively.

Electrical contacts 40, 41 are applied to the surface 34 making contact with the two n-type regions 36 and 37 respectively. Thus, when a positive voltage is applied to contact 40, and a negative voltage to the contact 41, the junction 38 will become reverse-biased, while the junction 39 becomes forward-biased, so that electrons will tend to be emitted from the line where the junction 38 intersects the surface 34. When the voltage is reversed, the junction 39 will tend to emit.

The cathode described with reference to Figures 4 and 5 may be constructed by any of the above-mentioned methods. For example, an annular groove may be cut in the layers 32 and 33, and the region 35 formed in this groove by epitaxial growth.

Reference may be made to the above-mentioned Patent Specification No. 1134681 for details of methods of cleaning the semiconductive material of the cathodes, and of treating the cathodes to increase the electron emission.

It will be appreciated that other cathodes in accordance with the invention may be of similar form to those described above by way of example, but with the conductivity type of each region reversed.

WHAT WE CLAIM IS:—

1. A cathode for use in an electric discharge device comprising a body of semiconductive material having at least one pair of regions of opposite conductivity type separated from each other by a p-n junction which intersects a substantially planar part of the external surface of the body in a closed loop, the cathode being such that a suitable reverse-bias voltage applied across the junction causes electrons to be emitted from the cathode, only in the vicinity of said loop where the p-n junction is exposed at the planar surface.

2. A cathode according to Claim 1 wherein said junction is annular in shape as herein defined.

3. A cathode according to Claim 2 including a layer of material of high resistivity, one said region comprising a layer of semiconductive material overlying the resistive layer, the surface of which semiconductive layer remote from the resistive layer lies in said substantially planar part of the surface, and the other said region comprising a body of semiconductive material extending from said substantially planar part of the surface through the first region into the resistive layer.

4. A cathode according to Claim 3 wherein said other region of semiconductive material extends through the resistive layer also, to the side of that layer remote from said substantially planar part of the surface.

5. A cathode according to Claim 4 wherein there is provided a further layer of semiconductive material on the side of said resistive layer remote from said substantially planar part of the surface, making ohmic contact with said other region of semiconductive material.

6. A cathode according to any one of Claims 1 to 3 wherein said regions comprise at least two regions of one conductivity type and a region of the opposite conductivity type separated therefrom by respective p-n junctions, each of which intersects the substantially planar part of the surface in a closed loop.

7. A cathode according to Claim 6 wherein one of said two regions of one conductivity type lies within the region of opposite conductivity type which in turn lies within the other of said two regions.

8. A cathode substantially as hereinbefore described with reference to the drawing filed with the Provisional specification.

9. An electric discharge device including a cathode as claimed in any preceding claim.

10. A cathode ray tube including a cathode as claimed in any one of Claims 1 to 8.

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